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An analysis of wind energy potential and economic evaluation in Zahedan, Iran

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ABSTRACT

Most people would produce their own clean local energy if it were easy and affordable. When a renewable energy system is installed, there is an upfront cost that can be partially or completely offset by various ways. Purpose of this study is to assess wind energy potential for the city of Zahedan in southeast part of Iran. Five-year (2003–2007) wind data has been analyzed to obtain wind power density and wind energy potential. Weibull density function has been used to determine the wind power density and energy of the region. Yearly mean Weibull parameters, k and c, were 1.155 and 3.401 (m/s). Obtained wind power and energy densities are 89.184 W/m^2, and 781.252 kWh/m^2 respectively. In short, economic evaluation and analysis of four different wind turbines are presented in this paper. In order to utilize wind energy, it is recommended to install Proven 2.5 kW model wind turbine in the region which is the most cost efficient option.

Contents

1. Introduction

The current trend of consuming fossil fuels in the world causes these resources to deplete within the next century [1]. On the other hand, using fossil fuels has negative environmental problems such as greenhouse effect, pollution to atmosphere, and soil and water contamination [2]. Many developed and developing countries around the world have adopted policies to harness renewable energies such as wind and solar in order to reduce their dependency on nonrenewable resources of energies [3].

Renewable or the so-called “green energy” like wind, solar, geothermal, and hydro power is inexhaustible, clean and free [4,5].

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Renewable energy supplies about 18% of the world's final energy demands [6]. Use of wind turbine for generating electricity is in combination with other energy resources like diesel generator since wind energy source is inherently stochastic in nature and therefore it is unreliable power source by itself in many locations [7]. In order to use wind energy in a region, the first step is to assess the potential and feasibility.

Main purpose of this study is to assess wind energy potential for the city of Zahedan in southeast part of Iran. Five-year (2003–2007) wind data has been analyzed to obtain wind power density and wind energy potential. The province is the windiest part in Iran at the height of 25 m. Therefore, it is expected that city of Zahedan has a good potential for installing wind turbines. Meteorological data for the site was obtained from Iranian Meteorological Organization [8]. The data is used to assess the potential of the region for installing wind turbines in order to generate electricity.

There are different distribution functions for determining the wind energy potential and energy output of any site, including Weibull, Rayleigh, Johnson, Pearson, and Chi-2 method [9–13]. Also, there are some non-normal distribution functions such as Weibull [14], squared normal [15], inverse Gaussian [16], and log-normal [17]. Most of the researchers are using Weibull distribution function for different applications, because of an acceptable accuracy level [9]. Among various mentioned methods for statistical distribution of wind speed data analysis, Weibull distribution function usually known as the most qualified function due to its simplicity and high accuracy was selected for this study.

The rest of this paper is structured as follows: Wind energy in the world and Iran are presented in Sections 2 and 3 respectively. In Section 4, description of Zahedan is discussed. In Section 5, methodology is described. In Section 6, statistical analysis is presented. Performance assessments of wind turbines are described in Section 7. Economic evaluation is done in Section 8. Finally, conclusion is drawn in Section 9.

2. Wind energy in the world

Wind energy is producing about 13,500 MW of power and ranks third among the renewable energy resources in the world [6]. Use of wind turbine especially in the recent decade has an increasing trend [19]. Fig. 1 illustrates Use of wind energy in the world from 1995 to 2010. Clearly, about 1.5% of the electricity in the world is generating by wind energy [20].

Wind capacity (Fig. 1) in the world was about 19,4154 MW up to the end of 2010. Almost every 3 years, wind capacity was doubled. Europe with 84,741 MW had the highest position in terms of total installed capacity. Next positions respectively belonged to Asia (59,722 MW), North America (44,948 MW), Oceania (2598 MW), South America (1222 MW), and Africa (926 MW) [19]. Till 2010, the first five countries in terms of installed wind turbine capacity were China, USA, Germany, Spain, and India [1]. Fig. 2 shows the top 10 countries in terms of installed wind turbine capacity up to 2010 [19].

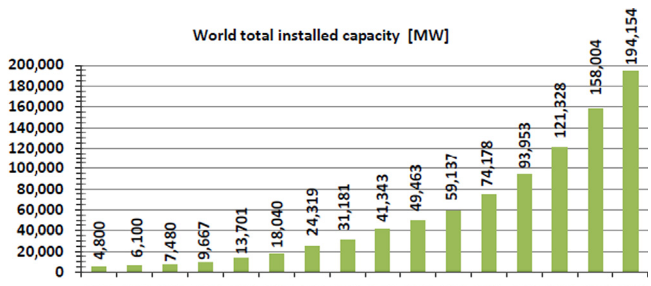

Fig. 1. Use of wind energy in the world [19].

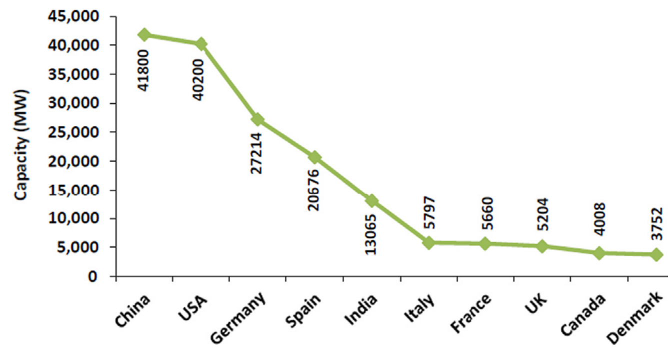

Fig. 2. Top 10 countries in terms of installed wind turbine capacity up to 2010.

Many researchers have investigated the wind potential and feasibility of installing wind turbines. Feasibility of installing wind turbine in some parts of Turkey [2,20,21], Greece [22,23], Germany [24], Ethiopia [25], Kingdom of Bahrain [26], Saudi Arabia [27], and Croatia [28] have been investigated.

3. Wind energy in Iran

Iran is located in a low-pressure location and has strong air flows in the summer and winter in some locations [3,29]. The country is influenced by two main winds:

(1) Winds from the Atlantic Ocean and Mediterranean Sea and also from central Asia in the winter.
(2) Winds from Indian Ocean and the Atlantic Ocean in the summer [3,29].

A study done by Sharif University in Iran, illustrates that in 26 locations of the country (including more than 45 sites) the wind energy potential is estimated about 6500 MW [3,29]. But its share in production of electricity using wind energy in the world is only 0.04% [1]. Fig. 3 illustrates the approximate map of wind currents in Iran at a height of 25 m [18]. It shows that major southeastern parts have very good potential for harnessing wind energy. However, this figure is an approximate map and for a detailed feasibility, we need doing some statistic calculation on the related data such as wind speed in a given region.

The first experience of Iran in installing wind turbines dates back to 1994. Two wind power plants of 500 kW were installed in Manjil and Roodbar in Gilan province in north of Iran. Their annual production of wind power is more than 1.8 million kWh [29]. The average of wind speed in Roodbar and Manjil areas are 15 m/s for 3700 h/yr and 13 m/s for 3400 h/yr, respectively. The second successful experience was in 1999 which 27 wind turbines were installed in Manjil, Roodbar and Harzevil. Harzevil is near Manjil which is about 1300 m above sea level and is about 500 m higher than Manjil. Manjil has 21 installed wind turbines, one 500 kW, five 550 KW and fifteen 300 kW [1,29]. Other locations of Iran having wind turbine are Binalood in Khorasan Razavi province with 66 turbines of 43,560 kW and Lutak in Sistan Baloochestan province with 1 turbine of 660 kW capacities [30]. The current capacity of generating wind power in Iran (Fig. 4) is around 92 MW [31] which is negligible if we compare it with 10 countries shown in Fig. 2. Clearly, China with 41,800 MW ranks first in the world.

Assessment of wind energy potential has been done for some locations of Iran such as Yazd [1], and Tehran [9], Semnan [24], and Manjil [32]. There are other literatures involving the analysis of wind energy potential and economic evaluation in Iran. Najfia and Ghobadian [33] reviewed wind energy resources and development

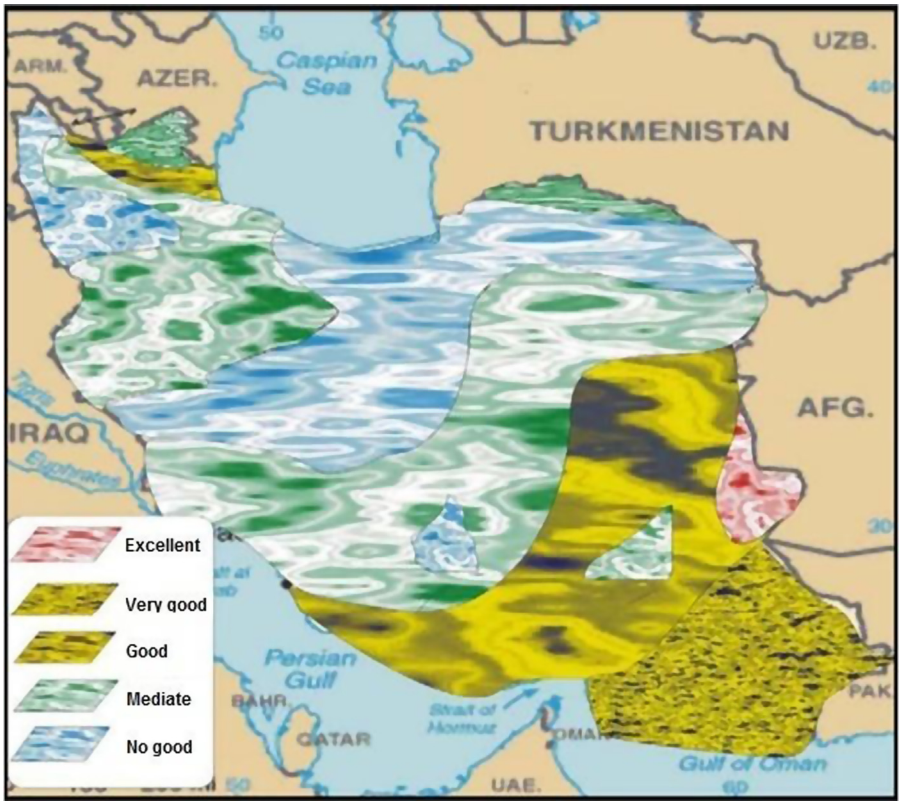

Fig. 3. Approximate map of wind currents in Iran at the height of 25 m [18].

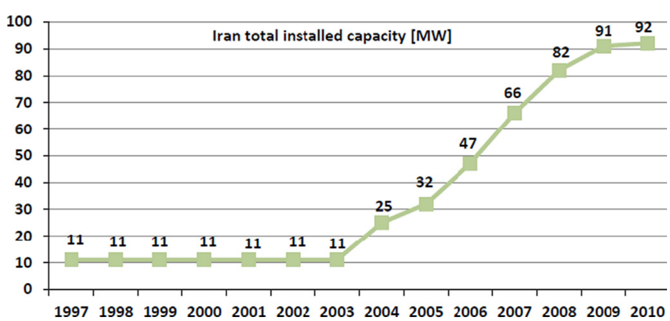

Fig. 4. Development of wind turbine installation capacity in Iran [31].

in Iran. They estimated that total wind turbine generation from the plants were 128 MW in 2008, also Iran ranked 38th in the world in 2009. They presented an introduction to the resource, status and prospect of wind energy in Iran. Ghoraishi and Rahimi [34] revealed renewable and non-renewable energy status, and the huge energy losses due to technological gaps and absence of relevant art of know-how in conventional energy industries in Iran. Bakhoda et al. [35] reviewed production trend and its effect on sustainable development of Iran in recent decades. They also discussed effect on sustainable energy production as one of the major part of sustainable development in too. Alamdari et al. [36] analyzed the potential of wind power generation in Iran by using wind speed data at 10 m, 30 m and 40 m heights for the year 2007. They estimated mean wind speed, the wind speed distribution function, and the mean wind power density for sixty eight different sites in Iran. Wind energy potential for Binalood in Iran was evaluated by Mostafaeipour et al. [37]. The yearly mean wind speed, mean power density and power density of Binalood at 40 m height were estimated. They found that Binalood had great potential for large wind turbine installation. Mostafaeipour [38] analyzed feasibility of harnessing wind energy for province of Yazd in Iran. He reviewed monthly and annual wind speeds at different heights over a period of 13 years between 1992 and 2005 from 11 stations. Mostafaeipour [39] carried out economic evaluation of small wind turbine utilization for city of Kerman in Iran. He analyzed economic evaluation and applications of three small wind turbines. The results indicated that the city had an available wind energy potential in order to install some small wind turbine models. Saeidi et al. [40] investigated feasibility of wind energy potential in two provinces of North and South Khorasan in Iran. They presented wind energy potential at four sites in two provinces. The objective was to evaluate the most important characteristic of wind energy for the studied areas. Wind speed data were analyzed by Weibull porbability function. The results indicated that the locations had good potential for harnessing wind energy. Dehghan [41] reviewed potential and status of renewable energies for Yazd province in Iran. The study showed that the region had great potentials for harnessing solar energy, but not good for wind turbine installation. Mousavi et al. [42] compared existing method of electricity generation with wind power in Iran. They mentioned that wind power can be as competitive as conventional power plants. Also, they suggested that the subsidies would affect the development of the Iranian wind power industry in the future.

In the present study, wind energy potential for city of Zahedan in Iran that is located in province of Sistan-Baloochestan is analyzed. Wind speed data for this study were taken from the Iranian Meteorological Organization. The main objective of this research work is to assess wind energy potential for the city of Zahedan.

4. Description of Zahedan

Zahedan (Fig. 5) is located in central part of Sistan-Baloochestan province in the southwest of Iran. It is located in 29°28/N latitude

Fig. 5. Map of Iran and location of Zahedan.

and 60°53/ longitude. The city is about 1370 m above the sea level [43]. The township of Zahedan is limited from north to Zabol county and South Khorasan province, from east to Afghanistan and Pakistan countries, from west to Kerman province and from south to Khash and Iranshahr cities [44].

Sistan-Baluchestan province accounts for one of the driest regions of Iran with a slight increase in rainfall from east to west, and an obvious rise in humidity in the coastal regions. The province is subject to seasonal winds from different directions, the most important of which are, the 120-day wind of Sistan known as Levar, the Qousse wind, the seventh (Gav-kosh) wind, the Nambi or south wind, the Hooshak wind, the humid and seasonal winds of the Indian Ocean, the North or (Gurich) wind and the western (Gard) wind [45].

5. Methodology

Knowledge of the wind speed frequency distribution plays a substantial role in order to estimate the potential of wind in any location. As long as the distribution of wind speed is known, both wind power potential and economic possibility of the site can be easily calculated. There are various probability density functions, which can be utilized to fit and describe the wind speed frequency over a period of time. These probability functions include the Weibull, Rayleigh, Gamma, Beta, Gaussian and Lognormal distribution. The two parameter Weibull distribution function usually known as the most qualified function due to its simplicity and high accuracy for wind speed data analysis. The Weibull probability density function is given as [2, 46–49]:

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (1)$$

where $f_w(v)$ is the wind speed probability for speed v, k is shape parameter (dimensionless) and c is scale parameter (m/s). The shape parameters, k, resemble the wind potential of the location and indicates how peaked the wind distribution is and the scale parameter, c, indicates how 'windy' a wind location under

consideration is. Several methods have been proposed to estimate the Weibull parameter. Some of these methods are:

(1) Graphical method
(2) Moment method
(3) Standard deviation method
(4) Maximum likelihood method
(5) Energy pattern factor method
(6) Power density method

In this study, the standard deviation method was used to obtain Weibull parameters. Using this method k and c are calculated respectively as [46–48]:

$$k=\left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \tag{2}$$

$$c=\frac{v}{\Gamma(1+1/k)} \tag{3}$$

In order to calculate the mean wind speed, v, and standard deviation of wind speed, σ, following expression can be used:

$$\overline{v}=\frac{1}{n}\sum_{i=1}^{n} v_i \tag{4}$$

$$\sigma=\left[\left(\frac{1}{n-1}\sum_{i=1}^{n}(v_i-\overline{v})^2\right)\right]^{0.5} \tag{5}$$

In terms of Weibull distribution function, $\overline{v}$ and σ can be obtained as follows [2,9]:

$$\overline{v}=\int_0^\infty v\, f_w(v)\, dv=c\,\Gamma\left(1+\frac{1}{k}\right) \tag{6}$$

$$\sigma=\sqrt{c^2\{\Gamma(1+2/k)-[\Gamma(1+1/k)]^2\}} \tag{7}$$

And also $\Gamma(x)$ is the gamma function and is given as follows [48,49]:

$$\Gamma(x)=\int_0^\infty \exp(-u)\, u^{x-1}\, dx \tag{8}$$

5.1. Wind power and wind energy density

In order to evaluate available wind resource at a site, it is required to calculate the wind power density. It shows how much energy is available at the site for conversion to electricity by wind. Wind power per unit area (A) can be calculated by:

$$P=\tfrac{1}{2}\rho\, v^3\ (W/m^2) \tag{9}$$

Based on Weibull probability density function, the wind power can be calculated using the following equation [46–49]:

$$\frac{P}{A}=\frac{1}{2}\rho\int_0^\infty v^3 f(v)\, dv=\frac{1}{2}\rho c^3\Gamma\left(1+\frac{3}{k}\right) \tag{10}$$

where ρ is density of air at the sea level and with a mean temperature of 15 °C and pressure of 1 atm or 1.225 kg/m^3. The corrected monthly air density (kg/m^3) is calculated as follows [9]:

$$\rho=\frac{\overline{P}}{R_d\overline{T}} \tag{11}$$

$\overline{T}$ is the average monthly air temperature in Kelvin, $\overline{P}$ is the average monthly air pressure in Pascal and R_d is gas constant for dry air with the value of 287 J/kg K. Air density decreases with increase of elevation and temperature [1]. Calculation shows that the difference between the corrected monthly air density and the standard one (ρ=1.225 kg/m^3) is small, thus for this study the standard air density is considered.

By obtaining the wind power density using Eqs. (9) and (10), the wind energy density for a specific period of time, T, can be obtained as:

$$E=PT \tag{12}$$

5.2. Wind speed extrapolation

Wind speed was measured at 10 m height for Zahedan during the study period. Clearly, wind blows slowly at low altitude and then increases at higher altitude. Consequently, since usually current wind turbines have hub heights higher than 10 m, the wind speed values should be extrapolated to hub height of turbines. Using Weibull distribution function, the shape parameter k_h and scale parameter c_h at desired height h are related to the shape parameter k_{10} and scale parameter c_{10} at measurement height of 10 m as [47,48]:

$$k_h=k_o/[1-0.088\ \ln(h/10)] \tag{13}$$

$$c_h=c_o(h/10)^n \tag{14}$$

where n is the power law exponent (coefficient) and is defined by [47,48]:

$$n=[0.37-0.088\ \ln(c_o)] \tag{15}$$

6. Statistical analysis

In this study, wind speed data from 2003 to 2007 was measured at 10 m has been statistically analyzed. The main obtained results are presented in the following:

6.1. Wind speed characteristics

The diurnal mean wind speeds are illustrated in Fig. 6. According to the figure, for all five years the maximum wind speed occurs at noon. It is clear that the day time is windier especially between 9 a.m. and 3 p.m. in comparison to the night time. The diurnal characteristics of wind speed illustrates that the wind speed increase from 3 a.m. till noon which reach to the highest values and later decrease. However, based on average of whole years the maximum hourly wind speed is equal to 5.52 m/s and occurs at noon, while the minimum is 1.34 m/s and occurs at 3 a.m. According to the diurnal variation of wind speed, it can be concluded that in case of installing wind turbines in Zahedan, the amount of electricity generation in the night time is very low.

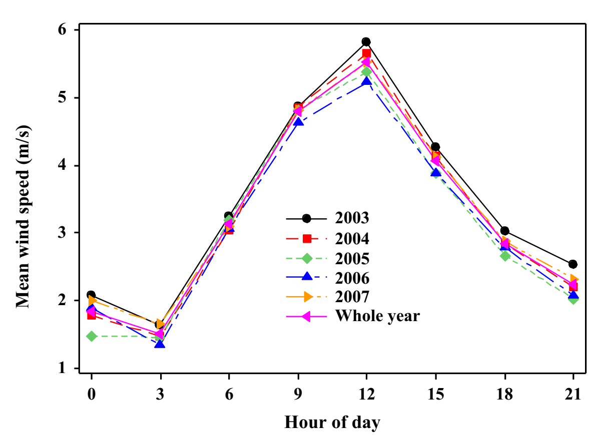

Fig. 6. Diurnal variation of wind speed at 10 m.

Monthly and annual mean wind speed as well as standard deviation for the years 2003 to 2007 are tabulated in Table 1.

According to the obtained results of Table 1, it is found that most of the monthly mean wind speeds are between 2 and 4 m/s, while only a few values are less than 2 m/s and over than 4 m/s. Furthermore, monthly analyses of wind data for all years indicate that the highest mean wind speed with value of 5.583 m/s occurred in February 2003 while the lowest mean wind speed is equal to 1.914 m/s and happened in October 2003. The monthly standard deviations range from 1.909 in October 2007 to 3.637 m/s in March 2003. Based on average of all years presented in the last column of table, the monthly mean wind speed varies from 4.269 m/s in February to 2.166 m/s in October. Also the maximum value of standard deviation is equal to 3.294 in March whereas the minimum one is equal to 2.108 in October. In terms of yearly values of mean wind speed and standard deviation, the results show that yearly wind speed varies from 3.108 in 2005 to 3.436 in 2003. In addition, the highest and the lowest yearly standard deviation are 2.834 and 2.560 and occur in 2004 and 2006, respectively. Also on the basis of average of whole years, yearly wind speed and standard deviation are equal to 3.238 and 2.722, respectively.

In order to make better sense about variation of wind speed in different months, the monthly mean wind speed for the years 2003–2007 as well as average of whole years are plotted in Fig. 7.

6.2. Analysis of Weibull parameters, power and energy densities

Table 2 illustrates the monthly mean shape parameter, scale parameter, power density and energy density. The shape and scale parameters are calculated using Eqs. (2) and (3). In order to calculate the wind power density and energy density the Eqs. (10) and (12) are used respectively. It should be mentioned these values were obtained based on average of all years. However, the results reveal that the shape and scale parameters are in the range of 1.025–1.361 and 2.188–4.618 m/s, respectively in different months of year. Moreover, it is observed that the highest and the lowest values of wind powers are equal to 162.557 W/m^2 and 35.113 W/m^2 and happen in February and October, respectively. The wind energy density values range from 26.124 kWh/m^2 in October to 118.645 kWh/m^2 in March.

The yearly mean values of shape and scale parameter, wind power and wind energy for different years from 2003 to 2007 as well as average of whole years are listed in Table 3. The results show that the maximum wind power and wind energy occur in 2003 with values of 106.525 W/m^2 and 933.159 kWh/m^2, respectively whereas the minimum values belong to 2006 and are equal to 72.777 W/m^2 and 637.527 kWh/m^2, respectively. Furthermore, average annual amount of shape parameter, scale parameter, power density and energy density for period of five years (2003–2007) are equal to 1.155, 3.401 m/s, 89.184 W/m^2 and 781.252 kWh/m^2, respectively.

Nonetheless, in order to determine the possibility of wind turbines utilization in each region, usually some wind classifications are used. In this study, to achieve this goal, Battelle-Pacific Northwest Laboratory (PNL) wind power classification scheme [50] are considered as benchmark. This classification has been developed for three heights of 10 m, 30 m and 50 m and divided the wind power to 7 different classes ranging from class 1 (lowest) to 7 (highest). The PNL wind power classification is presented in Table 4.

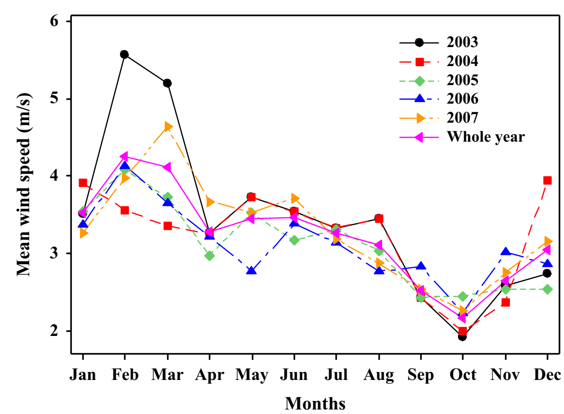

Fig. 7. Monthly variation of wind speed at 10 m.

Table 1
Monthly mean wind speeds and standard deviations.

Months	Parameters	2003	2004	2005	2006	2007	Whole year
Jan	*V*	3.512	3.912	3.543	3.377	3.263	3.521
	Σ	3.153	3.299	3.443	3.161	2.676	3.146
Feb	*V*	5.583	3.561	4.088	4.134	3.977	4.269
	Σ	3.518	3.120	3.451	3.169	3.155	3.283
Mar	*V*	5.198	3.354	3.721	3.655	4.638	4.113
	Σ	3.637	3.477	3.254	2.833	3.270	3.294
Apr	*V*	3.256	3.256	2.975	3.211	3.672	3.274
	Σ	2.842	2.842	2.349	2.577	3.319	2.786
May	*V*	3.731	3.731	3.520	2.767	3.530	3.456
	Σ	2.621	2.621	3.044	2.307	2.413	2.601
Jun	*V*	3.537	3.537	3.170	3.380	3.721	3.469
	Σ	2.636	2.636	2.518	2.450	2.790	2.606
Jul	*V*	3.327	3.327	3.310	3.136	3.186	3.257
	Σ	2.623	2.623	2.688	2.468	2.473	2.575
Aug	*V*	3.443	3.443	3.032	2.767	2.869	3.111
	Σ	2.734	2.734	2.620	2.152	2.413	2.531
Sep	*V*	2.418	2.418	2.431	2.821	2.529	2.523
	Σ	2.489	2.489	2.400	2.111	2.314	2.361
Oct	*V*	1.914	1.989	2.443	2.230	2.253	2.166
	Σ	2.255	2.135	2.167	2.076	1.909	2.108
Nov	*V*	2.572	2.366	2.533	3.018	2.752	2.648
	Σ	2.564	2.589	2.507	2.640	2.116	2.483
Dec	*V*	2.736	3.949	2.535	2.858	3.149	3.045
	Σ	2.664	3.437	2.543	2.774	3.047	2.893
Yearly	*V*	3.436	3.237	3.108	3.113	3.295	3.238
	Σ	2.811	2.834	2.749	2.560	2.658	2.722

Table 2
Monthly Weibull parameters (k, c), power, density and energy density.

Months	k	c (m/s)	P (W/m^2)	E (kWh/m^2)
Jan	1.125	3.675	122.046	90.802
Feb	1.302	4.618	162.557	109.238
Mar	1.241	4.409	159.469	118.645
Apr	1.181	3.465	88.625	63.81
May	1.343	3.766	81.957	60.976
Jun	1.361	3.788	81.011	58.328
Jul	1.291	3.522	73.558	54.727
Aug	1.24	3.334	69.101	51.411
Sep	1.072	2.592	49.947	35.962
Oct	1.025	2.188	35.113	26.124
Nov	1.066	2.715	58.502	43.525
Dec	1.036	3.089	95.169	70.806

Table 3
Yearly Weibull parameters (k, c), power density and energy density.

Year	$\boldsymbol{k}$	**c (m/s)**	**P (W/m^2)**	**E (kWh/m^2)**
2003	1.152	3.599	106.525	933.159
2004	1.119	3.375	96.130	842.099
2005	1.111	3.227	85.939	752.826
2006	1.203	3.302	72.777	637.527
2007	1.211	3.506	85.650	750.294
AVG	1.155	3.401	89.184	781.252

Table 4
PNL wind power classification [40].

Wind power class	10 m Wind power (W/m^2)	10 m wind speed (m/s)	30 m Wind power (W/m^2)	30 m wind speed (m/s)	50 m Wind power (W/m^2)	50 m wind speed (m/s)
1	≤ 100	≤ 4.4	≤ 160	≤ 5.1	≤ 200	≤ 5.6
2	≤ 150	≤ 5.1	≤ 240	≤ 6.0	≤ 330	≤ 6.4
3	≤ 200	≤ 5.6	≤ 320	≤ 6.5	≤ 400	≤ 7.0
4	≤ 250	≤ 6.0	≤ 400	≤ 7.0	≤ 500	≤ 7.5
5	≤ 300	≤ 6.4	≤ 480	≤ 7.5	≤ 600	≤ 8.0
6	≤ 400	≤ 7.0	≤ 640	≤ 8.2	≤ 800	≤ 8.8
7	≤ 1000	≤ 9.4	≤ 1600	≤ 11.0	≤ 2000	≤ 11.9

Table 5
Specification and price of considered wind turbines.

Wind turbine Model	Rated power (kW)	Rotor diameter (m)	Swept area (m^2)	Wind turbine price ($) [42]
Bergey XL.1	1.0	2.5	4.91	3450
Proven 2.5	2.5	3.5	9.63	6150
Southwest Whisper 500	3.0	4.5	15.91	10,433
Bergey Excel-R	7.5	6.7	35.27	27,000

According to PNL classification, Zahedan falls into class 1. Also the results of all years from 2003 to 2007 indicate that in all years except 2003 which falls in class 2, Zahedan ranked into class 1. In addition, in three months from January to march Zahehdan falls into class 2 and in the remaining months ranked in class1. Class 1 and 2 are usually considered as unsuitable and marginal locations, respectively [50]. It can therefore be concluded that the potential for wind energy development in Zahedan is limited. Nevertheless, this potential maybe appropriate for low capacity wind turbines in rural and small communities. In this regard, in order to perform a better decision making, in the rest of study in addition to testing the performance of four small scale wind turbines with different rated powers, the economic evaluations are also investigated.

7. Performance assessments of wind turbines

Four small size wind turbines models with rated powers ranging from 1 kW to 7.5 kW are chosen from different manufacture to simulate their performance in city of Zahedan. The specification and price of selected wind turbines are given in Table 5.

The power curves of the wind turbines are also shown in Fig. 8. In order to determine the amount of energy output and capacity factor values based on Weibull function, Windographer software was used [51].

These nominated wind turbines are designed for operation at different hub heights. In this study, the performances of turbines are tested at two heights of 20 m and 30 m. By using Eqs. (13)–(15) wind data values are extrapolated at 20 m and 30 m heights. Fig. 9 shows extrapolated values of wind speed at 20 m and 30 m in comparison to measured values at 10 m for different years and average of all years. With increasing the height from 10 m to 20 m and 30 m, the annual average of wind speed of all years increases from 3.23 m/s to 3.81 m/s and 4.22 m/s, respectively. It means 18% and 30% increase of annual wind speed respectively at 20 and 30 m elevations.

The annual capacity factor and energy output for all wind turbines at two hub heights of 20 and 30 m are illustrated in Figs. 10 and 11 respectively. In terms of capacity factor, it is clear

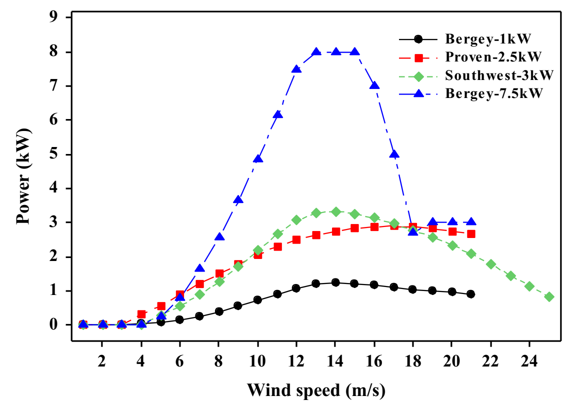

Fig. 8. Power curves of the considered wind turbines.

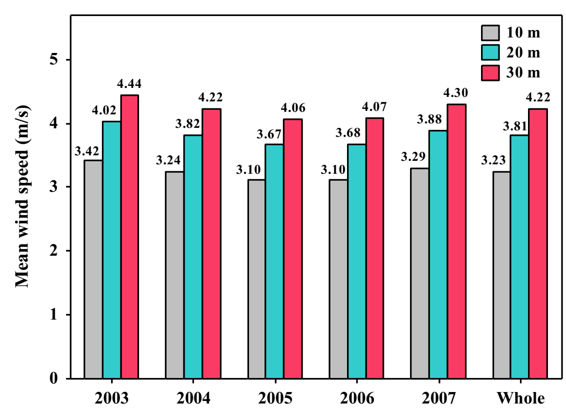

Fig. 9. Annual mean wind speed at three heights of 10, 20 and 30 m.

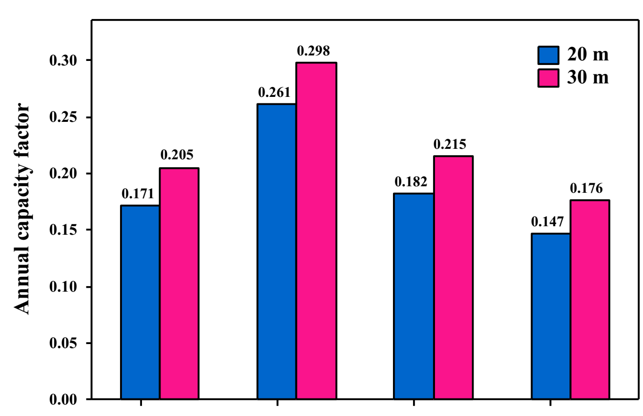

Fig. 10. Annual capacity factor of the wind turbines at 20 and 30 m.

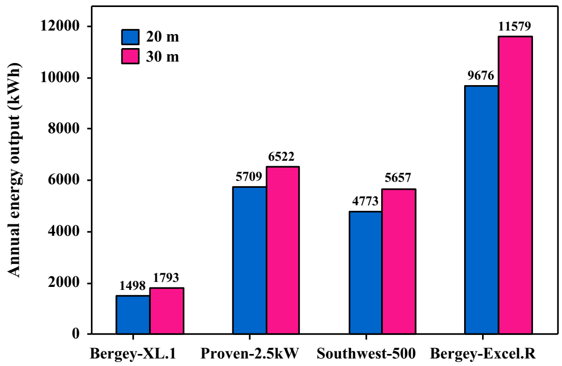

Fig. 11. Annual energy output of the wind turbines at 20 and 30 m.

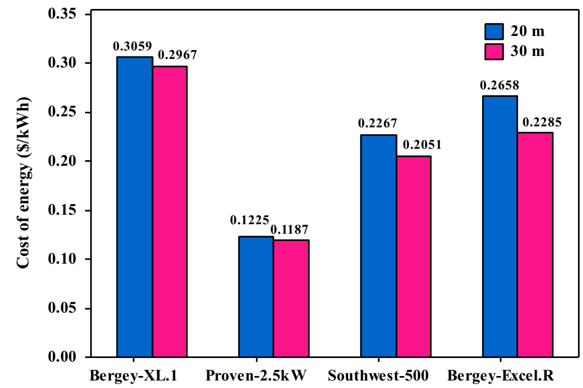

Fig. 12. Cost of electricity produced by wind turbines ($/kWh).

that Proven 2.5 turbine with rated power of 2.5 kW has the best performance. The capacity factor values for this turbine model at 20 m and 30 m hub heights are equal to 0.261 and 0.298, respectively. On the other hand, the Bergey Excel-R model turbine with rated power of 7.5 kW produced the highest amount of energy equal to 9676 kWh and 11,579 operational at 20 m and 30 m hub heights, respectively. Therefore, in terms of electricity production, Bergey Excel-R model is considered as the best option.

8. Cost estimation of energy output

Economic evaluation can compare the costs and consequences of different investments. The aim of economic evaluation is to ensure that the benefits from the projects are greater than the opportunity cost of such projects. It also provides criteria for deciding between different alternative projects that have different costs or consequences. Managements or decision makers need to know the inputs or costs that the projects will need as well as the outputs or benefits that the projects will produce. The decision makers can conduct economic evaluation to produce comprehensive results that are scientifically acceptable. Performance of economic evaluation is required for different wind turbines in order to identify the best model.

The method used in order to estimate the costs of energy is described as follows [52]:

Let C_I be the initial investment of the project and C_{OM} be the operation and maintenance cost including salary, insurance, tax, rent, and salvage value. Expressing the C_{OM} as a percentage m of C_I

$$C_{OM} = mC_I \tag{16}$$

Now, discounting the operation and maintenance costs for n years to the initial year,

$$PV(C_{OM})_{1-n} = mC_I\left[\frac{(1+I)^n-1}{I(1+I)^n}\right] \tag{17}$$

where I is the Interest rate.

Including the initial investment C_I, the accumulated net present worth of all costs is:

$$\mathrm{NPV}(C_A)_{1-n} = C_I\left\{1+m\left[\frac{(1+I)^n-1}{I(1+I)^n}\right]\right\} \tag{18}$$

Therefore, yearly operational cost of r the turbine is:

$$\mathrm{NPV}(C_A) = \frac{\mathrm{NPV}(C_A)_{1-n}}{n} = \frac{C_I}{n}\left\{1+m\left[\frac{(1+I)^n-1}{I(1+I)^n}\right]\right\} \tag{19}$$

Hence, the output energy produced by the turbine in one year is:

$$E_{out} = 8760\, P_r\, C_F \tag{20}$$

Thus, the cost of kWh wind-generated electricity is given by:

$$C = \frac{NPV(C_A)}{E_{out}} = \frac{C_I}{8760\,n}\left(\frac{1}{P_r\,C_F}\right)\left\{1+m\left[\frac{(1+I)^n-1}{I(1+I)^n}\right]\right\} \tag{21}$$

where P_r and C_F are rated power and capacity factor of wind turbine.

Following assumption are made in this study for cost estimation:

(1) The other initial costs including installation, transportation, custom fee and grid integration are assumed 40% of the turbine cost.
(2) The interest rate (I) is 21%.
(3) Annual operation and maintenance costs plus the land rent is about 6% of the turbine cost.
(4) The useful life of the wind turbines is 20 years.

The costs for each meter tower for all selected wind turbines are considered $116.67 [53]. To illustrate, for the wind turbine with tower of 20 m, the total cost of tower is equal to $2333.4 and should be added to the cost values presented in Table 5 in order to calculate the total cost of wind turbines. Fig. 12 presents the cost of per kWh energy output from nominated wind turbines at two heights of 20 and 30 m. It is found that with increasing the hub height, the cost of energy reduces for all turbines.

Nonetheless, the minimum cost of energy is obtained using Proven 2.5 kW which the values at hub heights of 20 m and 30 m are equal to 0.1225 $/kWh and 0.1187 $/kWh, respectively. On the other hand, the maximum energy cost is achieved with Bergey XL.1 kW. For this wind turbine model, the energy cost at 20 and 30 m hub heights are 0.3059 $/kWh and 0.2967 $/kWh, respectively. From the results it can be concluded that, in spite of the fact Bergey Excel-R model with 7.5 kW rated power generates the highest amount of electricity, the Proven 2.5 kW model is the most economical wind turbine model. Currently, in Iran the purchase tariff for electricity generated by renewable energies like wind approved by government is about 0.13 $/kWh [54]. By comparing the obtained results presented in Fig. 10 with purchase tariff of renewable energy, it is found that installation of only proven 2.5 kW model wind turbine is economically feasible for Zahedan.

9. Conclusions

An alternative to overcome the disadvantages of the use of fossil fuels, is the implementing of wind energy systems or wind turbines. The present trend of consuming fossil fuels is alarming in the future. On the other hand, environmental problems with fossil fuels are becoming a serious concern for people in many countries.

The best alternative for combating this situation is to utilize renewable energy sources such as wind. Electricity generation using wind energy has been done by many countries for decades and the trend is increasing. For this purpose, assessment of the wind energy potential for a given location is the first stage. The findings for feasibility of implementing wind energy technology for city of Zahedan were as follows:

- Assessment of wind energy potential for city of Zahedan (in the southeast of Iran) has been done. The three-hourly wind data for a period of 5 years has been statistically analyzed using Weibull distribution.
- For all five (2003–2007) years the maximum wind speed occurs at noon. It is clear that the day time is windier especially between 9 a.m. and 3 p.m. in comparison to the night time. The diurnal characteristics of wind speed illustrates that the wind speed increase from 3 a.m. till noon which reach to the highest values and later decrease.
- However, based on average of whole years the maximum hourly wind speed is equal to 5.52 m/s and happens at noon, while the minimum is 1.34 m/s and occurs at 3 a.m. According to the diurnal variation of wind speed it can be concluded that in case of installing wind turbines in Zahedan, the amount of electricity generation in the night time is very low.
- It is found that most of the monthly mean wind speeds are between 2 and 4 m/s, while only a few values are less than 2 m/s and over than 4 m/s. Also on the basis of average of whole years, yearly wind speed and standard deviation are equal to 3.238 and 2.722, respectively.
- The results show that the maximum wind power and wind energy occur in 2003 with values of 106.525 W/m^2 and 933.159 kWh/m^2, respectively whereas the minimum values happen in 2006 and are equal to 72.777 W/m^2 and 637.527 kWh/m^2, respectively. Furthermore, average annual amount of shape parameter, scale parameter, power density and energy density for five years period (2003–2007) are equal to 1.155, 3.401 m/s, 89.184 W/m^2 and 781.252 kWh/m^2, respectively.

  Economic evaluation was performed on four different wind turbine models of Bergey XL.1, Proven 2.5, Southwest Whisper 500, and Bergey Excel-R. The minimum cost of energy is obtained using Proven 2.5 kW which the values at hub heights of 20 m and 30 m are equal to 0.1225 $/kWh and 0.1187 $/kWh, respectively. On the other hand, the maximum energy cost is achieved with Bergey XL.1 kW. For this wind turbine model, the energy cost at 20 and 30 m hub heights are 0.3059 $/kWh and 0.2967 $/kWh, respectively. From the results it can be concluded that, in spite of the fact Bergey Excel-R model with 7.5 kW rated power generates the highest amount of electricity, the Proven 2.5 kW model is the most economical wind turbine model.

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